$\omega\gamma$ for ^{19}Ne$(p,\gamma)^{20}$Na(2.64 MeV)

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Recent information concerning the ^{20}Na level at 2643 keV is still consistent with a J^π assignment of 3^+. We use new experimental information on the mirror γ-decay width, together with an evaluation of the isospin nonconserving effects, to obtain $\omega\gamma \geq 16$ meV for the ^{19}Ne(p,γ) reaction which is of interest for the astrophysical rapid-proton capture process.

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The level at 2643 keV in ^{20}Na is the first level above threshold in the ^{19}Ne$(p,\gamma)^{20}$Na reaction and is important for the rapid proton (rp) capture process in explosive hydrogen burning. The quantity of interest is the $\omega\gamma$ for this reaction defined by

$$\omega\gamma = \frac{(2J_R+1)}{(2J_p+1)(2J_T+1)}\frac{\Gamma_{p0}\Gamma_\gamma}{\Gamma},$$

where J_R, J_p, and J_T are the spins of the resonance, projectile, and target states, respectively, and Γ_{p0}, Γ_γ, and Γ are the ground-state proton decay, the γ-ray decay, and total widths of the resonance, respectively. In Ref. [1] it was suggested that the 2643 keV level was the analog of the 2966 keV 3^+ state in ^{20}F. From the decay properties of this 2966 keV level as known in 1993 and shell-model calculations, Brown *et al.* [1] obtained $\omega\gamma = 80$ meV. A recent ^{19}Ne radioactive beam experiment obtained a limit of $\omega\gamma \leq 21$ meV [2]. In the present Brief Report we reconsider the evaluation of the theoretical $\omega\gamma$ using more recent data and considering possible isospin asymmetry in the widths. The new value we obtain for the same 3^+ assignment is consistent with the experimental limit and suggests that it should be observable in an improved radioactive beam experiment.

There are no levels in ^{20}F [3] between 2194 and 2865 keV in excitation energy. Hence the mirror of ^{20}Na(2643) must be at or above 2865 keV. The large difference in excitation energy is indicative of significant parentage containing a $2s_{1/2}$ nucleon. The large energy shift associated with the $2s_{1/2}$ orbit is evidenced by the $0^+,1^+$ pair at 3526 and 3488 keV in ^{20}F and 3086 and 3001 keV in ^{20}Na. Beta decay [4] has established the mirror nature for the 1^+ members at 3488 and 3001 keV. The mirror of ^{20}Na(2643) almost certainly comes from among the ^{20}F states at 2865, (3^-); 2966, 3^+; 2968, (4^-); and 3172, $(0^-,1^+)$. Of these, only the 3^+ state is expected to contain a large $2s_{1/2}$ single-particle occupancy.

The other three levels are undoubtedly core-excited states. Negative-parity five-particle one-hole $(5p\text{-}1h)$ states are de-

scribed as ^{21}Ne$\times\pi^{-1}$ in ^{20}F and ^{21}Na$\times\nu^{-1}$ in ^{20}Na. For a $1p_{1/2}$ π or ν hole, the J^π of the (sd) [5] coupling, in order to make 3^- on 4^- states, would be $5/2^+\text{-}9/2^+$. None of these states in ^{21}Ne, ^{21}Na exhibit large excitation energy differences. The 3172 keV level of ^{20}F is probably 1^+, of $6p\text{-}2h$ character. A probable 1^+ assignment and the $6p\text{-}2h$ suggestion come from the reaction [5] ^{18}O$(^3$He$,p)$. Other information is primarily from compound-nucleus reactions, which establish low spin. In comparison of the magnitudes of the cross sections from ^{20}Ne$(^3$He$,t)$ and ^{20}Ne$(t,^3$He$)$ to mirror states [6], the ratio is approximately constant for all known (or suspected) mirror pairs. However, the cross section for ^{20}Na(2643) is about an order of magnitude too strong to be the mirror of ^{20}F(3172), but is consistent with ^{20}F(2966).

The original evaluation by Brown *et al.* [1] of $\omega\gamma = 80$ meV for the 3^+ state was based upon (1) $\Gamma_\gamma = 0.12$ eV from the calculated lifetime of 5.5 fs, (2) $\Gamma_{p1} = 0.73$ eV for the $l=0$ proton decay to the first excited $5/2^+$ state in ^{19}Ne from the calculated spectroscopic factor of $S_{th}(p1) = 0.35$, and (3) $\Gamma_{p0} = 0.52$ eV for the $l=2$ proton decay to the $1/2^+$ ground state from the spectroscopic factor of $S_{expt}(p0) = 0.054$ measured in the mirror ^{19}F$(d,p)^{20}$F reaction $[S_{th}(p0) = 0.068]$.

If we adopt the most recent result [7] of $\tau \leq 12$ fs for ^{20}F$(3^+,2966)$, then $\Gamma_\gamma(^{20}$F,2966$) \geq 55$ meV. Using the ratio of the calculated γ widths we obtain $\Gamma_\gamma(^{20}$Na,2646$) \geq 35$ meV. With this change alone we obtain $\omega\gamma(^{20}$Na(2643)$) \geq 25$ meV—tantalizingly close to the experimental upper limit of 21 meV [2].

An assumption made in the original calculation was that the mirror spectroscopic factors were equal. We have recalculated the spectroscopic factors using wave functions that take into account the Coulomb, charge asymmetric, and charge dependent interactions [8]. The parameters of these interactions were obtained from fits to the b and c coefficients of the isobaric multiplet mass equation for observed multiplets in the sd shell. We use the isospin-nonconserving (INC) interaction parameters from Table 2 of Ref. [8] with

the modification that the single-particle energy for the $2s_{1/2}$ orbital was adjusted to reproduce the observed shift in A = 17. (The single-particle energies given in Table 2 of Ref. [8] are those appropriate for the average of the entire sd shell where the relatively large binding energy of the $2s_{1/2}$ state in the middle and end of the shell leads to a rather small single-particle Thomas-Ehrman shift. At the beginning of the sd shell the $2s_{1/2}$ orbital is more loosely bound and requires a large Thomas-Ehrman shift as observed in Fig. 4 of Ref. [8] and discussed in the text there.) For the 3^+ state of interest, $b_{expt}=4.05$ MeV as compared with $b_{th}=4.08$ MeV with the INC interaction.

The results of these INC calculations are, for ^{20}F, τ_{th} = 3.5 fs, $S_{th}(p0)=0.073$, and $S_{th}(p1)=0.36$, and for ^{20}Na, $\tau_{th}=5.3$ fs, $S_{th}(p0)=0.040$, and $S_{th}(p1)=0.41$ in ^{20}Na. The main difference with the original good-isospin calculation is the large mirror asymmetry in the $S(p0)$ value. If we take the experimental value of $S_{expt}(^{20}\text{F},p0)=0.054$ together with the theoretical ratio, we obtain $S(^{20}\text{Na},p0)$ = 0.029 and $\Gamma(^{20}\text{Na},p0)=0.28$ eV. With only this change, the original value of $\omega\gamma=80$ meV is reduced to $\omega\gamma$ = 52 meV.

The isospin mixing effect together with the new limit on the ^{20}F lifetime discussed above would give $\omega\gamma_{th}$ ⩾ 16 meV. Comparison with the new experimental limit of $\omega\gamma_{expt} \leqslant 21$ meV ^{2} suggests that the actual value is close to 18 meV, and that an improved radioactive beam experiment may be able to measure this important quantity. It would also imply that the lifetime for the 3^+ 2966 keV level in ^{20}F should be close to its experimental limit [7] of $\tau \leqslant 12$ fs. The astrophysical implications of these results are discussed in Ref. [2].

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